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Harvesting Energy Chips from Forest Residues—Some Concepts for the Southern Pine Region

Peter Koch

SUMMARY

Residues from southern forests include tops, branches, central root systems, brush, cull trees, trees of unmerchantable species, and trees too small for economic harvest by conventional methods. Before such residues can be used by industry to produce energy, they must be reduced to chip form and delivered to mill stockpiles at a cost that will permit proposed wood-energy processes to operate competitively. Processes, for which wood chips are the feedstock, include combustion, gasification, pyrolysis, liquefaction, and hydrolysis and fermentation.

This paper describes and illustrates about a dozen harvesting methods which can be classified according to procedure as follows:

- Chip whole trees at the stump.
- Extract sawlogs at the stump; bunch and forward branches.
- Chip whole trees at the landing.
- Extract sawlogs at the landing; then chip, chunk, or bale branches.
- Chip residues at the mill.
- Transport complete trees to the mill (stem, crown, roots, and foliage); at mill, divert tree portions to use of highest value.

The cost of energy chips delivered into mill stockpiles, including 30-percent pre-tax profit on harvesting investment, will likely range from $18 to $33 per ton (green-weight, 1980 basis).

Harvesting Energy Chips from Forest Residues—Some Concepts for the Southern Pine Region

Peter Koch

INTRODUCTION

This report on procedures for harvesting southern forest residues is a companion publication to a previous report (Karchesy and Koch 1979) on methods of producing energy from hardwoods growing on southern pine sites.

Forest residues from southern pine sites include tops, branches, central root systems, brush, cull trees, trees of unmerchantable species, and trees too small for economic harvest by conventional methods. Before such residues can be used by industry to produce energy, they must be delivered to mill stockpiles at a cost that will permit proposed wood-energy processes to operate competitively. Usually the residues must be reduced to chip form.

While much of the total residue volume per acre is in stump-root systems (fig. 1), and some is in small pine culls and pine logging slash, the preponderance of the volume is in unmerchantable and cull hardwood trees. Such trees are typically small in diameter, short, and crooked. Low volume per stem and per acre and highly variable species mixes from site to site and from stand to stand combine to raise harvesting costs. Five of the major species, sweetgum, black tupelo, yellow-poplar, sweetbay, and sugarberry, have undivided central stems typical of excurrent growth. (fig. 2, left); this growth pattern eases harvesting problems. Sixteen of the species (the oaks, hickories, elms, and red maple), however, have forked stems typical of decurrent growth (fig. 2, right) that make harvesting them difficult and costly. The ash species are intermediate in growth form, but have widely spreading crowns.

Moreover, many pine-site hardwoods grow on terrain that is ill-suited for harvesting equipment. Examples are the steep, rocky slopes of the Arkansas and Virginia mountains, and the soft ground of the rain-saturated, rock-free, flat-to-rolling coastal plains in winter.

Proposed in this paper are partial solutions only, and some concepts for consideration. Significantly increased research and development work on logging systems and equipment appropriate for the resource are essential to fully adequate solutions (Boyd et al. 1977). Such work should be carried out at numerous centers because failures will outnumber successes. The rarity of technological breakthroughs over the decades attests to the difficulty of developing efficient harvesting techniques for the pine-site hardwoods.

Harvesting methods are influenced not only by terrain features, soil characteristics, weather, and ecological considerations, but also by stand density, diameter distribution, species mix, scale of the harvesting operation, tract size, and the purpose for which the trees are logged, i.e., for fuel, pulpwood, solid wood products, or chemical products. My initial assumption—that energy wood will usually be delivered to the energy-producing plant in chip form—somewhat defines harvesting procedures.

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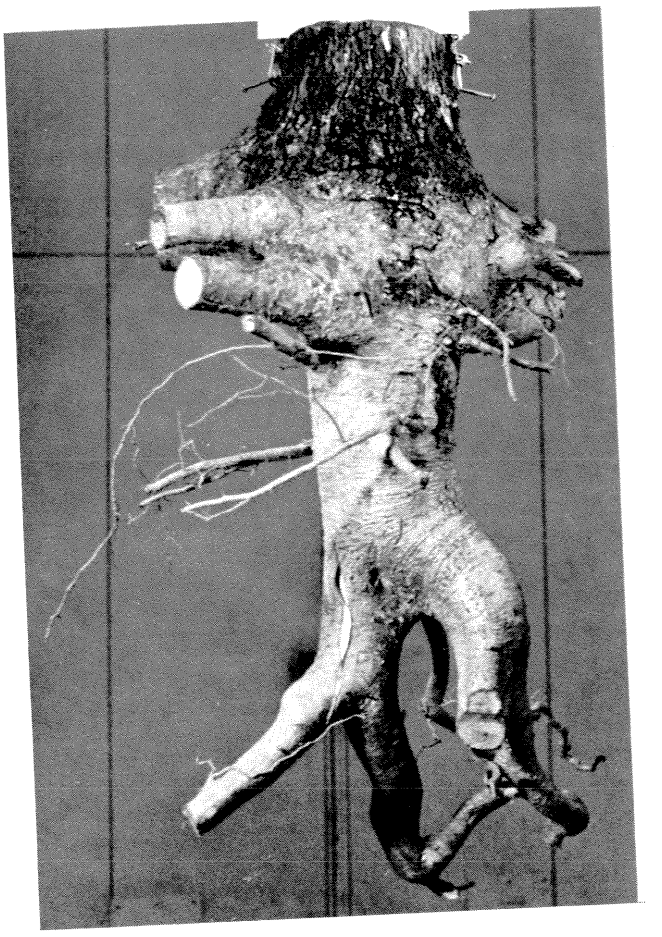


Figure 1.—*Central stump-root systems. (Left) Southern pine. (Right) Sweetgum.*

CHIP WHOLE TREES AT THE STUMP

The problem of accumulating logging slash, or pine-site hardwoods with their widespread strong limbs, into compact bundles for skidding or cable yarding is difficult; chipping whole trees at the stump is one alternative.

Felling-bar harvester.—Five timber companies with southern operations and Nicholson Manufacturing Company cooperated with the Southern Forest Experiment Station of the U. S. Forest Service (with substantial financial assistance from the Department of Energy) to develop a commercial prototype of a swathe-felling mobile chipper. From many proposed designs, a mobile chipper with a ground-level cylindrical felling bar feeding a drum chipper was adopted (fig. 3).

Performance goals required that the chipper:

- Operates primarily on terrain that is relatively stone-free, has a slope of 30 percent or less, and supports 9 psi in track pressure. In follow-up designs, a track pressure of 8 psi will be the goal; 6 psi would be preferable.
- Harvests 1 acre per hour at 1 mile per hour on land averaging 25 tons (green weight) of logging residue and standing culls per acre.
- Fells and chips standing stems of southern hardwoods and softwoods up to 12 inches in diameter (measured 6 inches above ground level) while moving at 1 mile per hour.
- Mills off the tops of 12-inch-diameter stumps to 6-inch height while traveling at 1 mile per hour (larger stumps at lower speeds).
- Picks up and feeds into the drum chipper tops, branches, and cull stem sections residual from logging operations.
- Chips felled stems up to 19 inches in diameter if properly oriented to the chipper infeed and with heavy lateral branches severed or notched to ease crown compaction.

The commercial prototype was assembled on the chassis of an FMC forwarder equipped with extended tracks (fig. 4, bottom). The machine has a 575-horsepower diesel engine which powers all functions including propulsion. Specifications are as follows:

Gross vehicle weight	73,000 pounds
Approximate ground contact area with 2-inch penetration of tracks	6,740 square inches
Approximate ground pressure	10.7 psi
Drum chipper characteristics	
Cutting circle diameter	48.0 inches
Spout width	47.5 inches
Number of knives	3
Rake angle of knives	52.5°
Drum speed	544 rpm
Nominal feed speed	136 feet per minute
Felling-bar characteristics	
Cutting-circle diameter	16.5 inches
Length	93.5 inches
Number of knives	4
Rake angle of knives	38.5°
Rotational speed	0-600 rpm
Clearance above ground	2 to 7 inches
Diameter of side feed rolls	24 inches
Machine ground speed	Creeping to 3 miles per hour

In operation, chips from the drum chipper are blown to the rear of the moving machine into one of a pair of self-powered tracked vehicles, each carrying a quick-dump chip bin with 10-ton holding capacity (fig. 4, top). Average speed of the mobile chipper should be 1 mile per hour over rock-free terrain of less than 30-percent slope that will support 10 psi ground pressure. At this speed the harvester will cover about 1 acre per hour on land averaging 25 tons (green weight) per acre of logging residues in the form of tops and limbs, standing cull trees, and stumps. About 85 percent of such residue should be recovered as chips and delivered into roadside piles at about $11.85 per green ton including 30 percent pretax profit on equipment investment (1977) of $470,000. When scheduled 7 days a week and 9.5 hours a day, the machine should harvest about 1500 acres per year (Koch and Nicholson 1978).

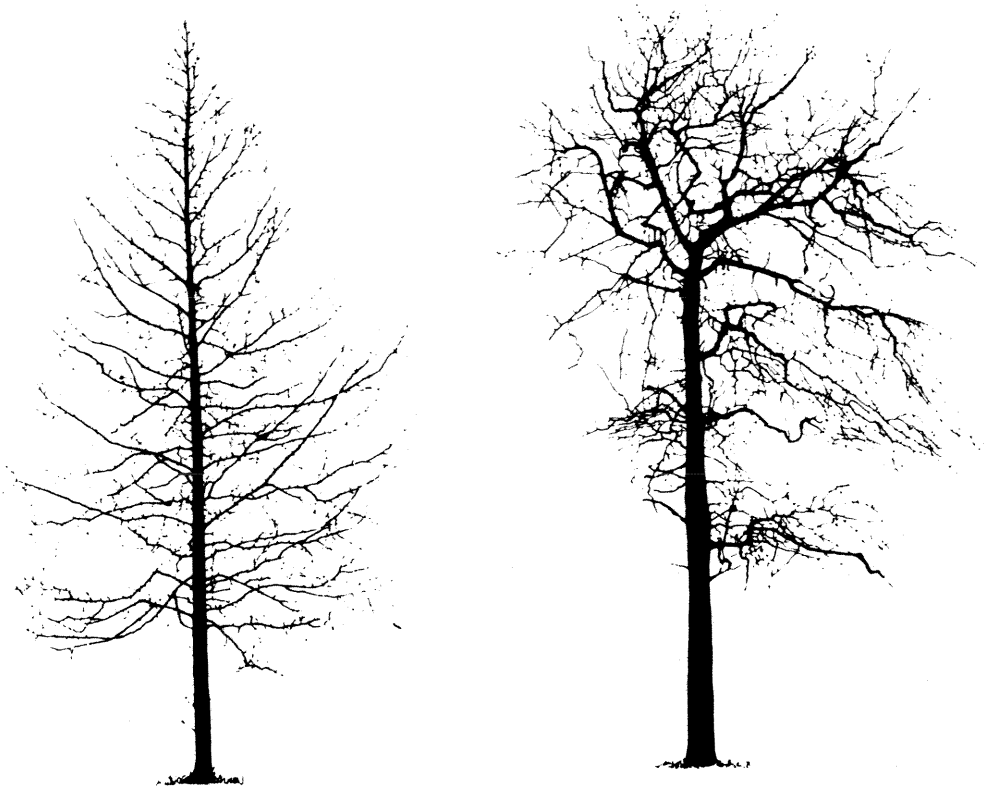
If this system can be put into successful operation, it will provide mills with wood for fuel and fiber that would otherwise be wasted; the system also has numerous other benefits:

- Changes some of the capital investment for site preparation to a harvesting expense.
- Should improve public reaction to harvesting because it eliminates waste wood and unsightly slash.
- Avoids the smoke of windrow and burn operations.
- Compared with the windrow and burn system, increases plantable area (by perhaps 10 percent)—because not all windrows are completely burned.
- Increases land productivity, because scalping inherent in pile and burn operations is eliminated.
- Hastens replanting by several months because harvesting accomplishes site preparation.
- Wood harvested is forest residual chips (rather than chunks or shreds) which have high potential for fiber products more valuable than energy.
- Because no wood is skidded over the ground, wood delivered via mobile chipper and chip forwarding bins should be relatively free of dirt.

The swathe-felling mobile chipper equipped with felling bar is currently undergoing extensive tests on southern lands of the U.S. Forest Service and the five industrial cooperators. Performance data should be available in 1981.

Circular-saw harvester.—An alternative design for a swathe-felling mobile chipper severs stems and feeds a disk chipper with dual ground-level circular saws counter-rotating toward each other (Smith and O'Dair 1980). NFI, Inc., Alexandria, La., cooperated with Georgia-Pacific Corporation to build a brush harvester on this principle (fig. 5). All functions of the harvester are driven by a 430-horsepower diesel engine. The tracked machine weighs 48,000 pounds when carrying a 6,000-pound chip load and exerts a ground pressure of 8.3 psi. The 16-tooth cutter disks remove a 2¼-inch kerf and cut a 7.5-foot swathe. Trees and brush 5 inches in dbh and smaller are easily felled and efficiently fed into the chipper. Design ground speed is about 1 mile per hour. The machine as originally built was priced (1978) at about $245,000, and had hourly production of about 6 tons (green basis) of whole-tree chips.[1] The machine illustrated in figure 5 must cease harvesting each time the

[1]Koch, P. 1977. Correspondence relative to Study FS-SO-3201-2.81, Southern Forest Experiment Station, USDA Forest Service, Pineville, La.



1-Foot Radius Lateral Root System

Tree Part	Percent
Foliage	3.2
Branches and Twigs	18.5
Stem	63.0
Stump-root System	15.3
	100.0

Figure 2.—*Typical stem and branch patterns, and average biomass distribution (dry-weight basis) of 6-inch diameter hardwoods of the major species growing on southern pine sites. (Left) Excurrent growth of sweetgum. (Right) Decurrent growth of blackjack oak. (Drawings after Brown and Grelen 1977.)*

chip bin is filled, travel to roadside to empty its load onto a roadside chip pile, and then return to where harvesting was discontinued.

To avoid such discontinuous harvesting, the Pallari harvester, which operates on a similar felling and chipping principle (fig. 5A), discharges chips into portable chip sacks which are thrown from the harvester when filled. Use of sacks gives the harvester maneuverability around obstacles and enables it to reverse; also it permits formation of a small buffer storage in the forest. Disadvantages include additional original investment in sacks and costs of sack repair; also the sacking system requires at least one extra hand for the harvester and another for unloading sacks at roadside. Readers interested in the system are referred to Hakkila and Kalaja (1980) who have provided operational data on the machine.

Manual felling and farm-tractor chipping.—The systems just described use complex heavy machinery involving substantial investments. There are simple alternatives requiring less capital but more labor. For example, using light farm machinery (fig. 6) a man can harvest during 1 working day about 4.3 tons of green whole-tree chips equal in fuel value to 1 ton (286 gallons) of oil. (A gallon of number 2 heating oil weighs 7.0 pounds and has a heat content—135,000 Btu—equal to about 30

pounds of green whole-tree chips of pine-site hardwoods.) At $1.00 per gallon, 286 gallons of heating oil (1 ton) will cost $286.

The poorer burning efficiency of wood, the high cost of wood-fueled burners compared to oil burners, and the inconvenience of handling wood make it doubtful that a seasonal worker could sell his day's output (4.3 tons of green chips) for $286, but he might—in the not too distant future—get $143 (or $33 per ton) delivered to the user's fuel pile.

The low-investment harvesting shown in figure 6 would be ecologically acceptable to many southern farmers and woodlot owners. Each worker in the two-man team might earn $143 per day, less his share of stumpage, daily cost of the chainsaw and simple harvester, and cost of trucking 8.6 tons to the customer's fuel pile. Thus, when energy chips reach a value of $33 per ton, a farm woods worker cutting fuel chips might pocket $100 per day with very low capital investment.

Intermediate between the low-investment concept of figure 6 and the high-investment system shown in figure 4, are several arrangements whereby tractor-powered chippers operate along strip roads. Trees are dragged from distances of about 150 feet to the chippers by light winches, or small tractors. If strip roads can be spaced closely (e.g., 110 feet apart), long-reach sliding-boom cranes can grip the trees after felling, draw them to the strip road, and feed them into moderately powered chippers. Chips can be blown into pallets or quick-dump bins for forwarding to highway trucks. These Scandinavian systems are further described by Nilsson (1978), Kalaja (1978), Hakkila (1978), and Hakkila et al. (1979).

EXTRACT SAWLOGS AT THE STUMP—BUNCH AND FORWARD BRANCHES

When logging hardwood timber that is of quality good enough to contain sawlogs or veneer logs, it is usual practice to sever the crowns from the stems and leave them near the stump as logging slash. If the massive crowns are then skidded to a roadside chipper, they can cause much damage to residual trees. Moreover, the heavy limbs of many species are so inflexible that they must be notched by chainsaw before they can be compressed for chipping by the feedrolls of a roadside chipper (fig. 7). Such notching is hard work and dangerous.

A mechanized alternative procedure was proposed by Mattson et al. (1978). By this system, crowns too massive for the whole-tree chipper would be severed from the felled and bunched tree. After the stemwood is skidded away, a small, highly maneuverable, hydraulically actuated shear mounted on a knuckle boom of a vehicle (fig. 8) would sever large protruding limbs and align them with the butt of the main stem of the top. Thus compacted, the top is grapple skidded to the whole-tree chipper. In 1978, the cost per green ton to shear and compact the tops, skid them to roadside, and chip them was estimated at $6.32 per ton, green basis.

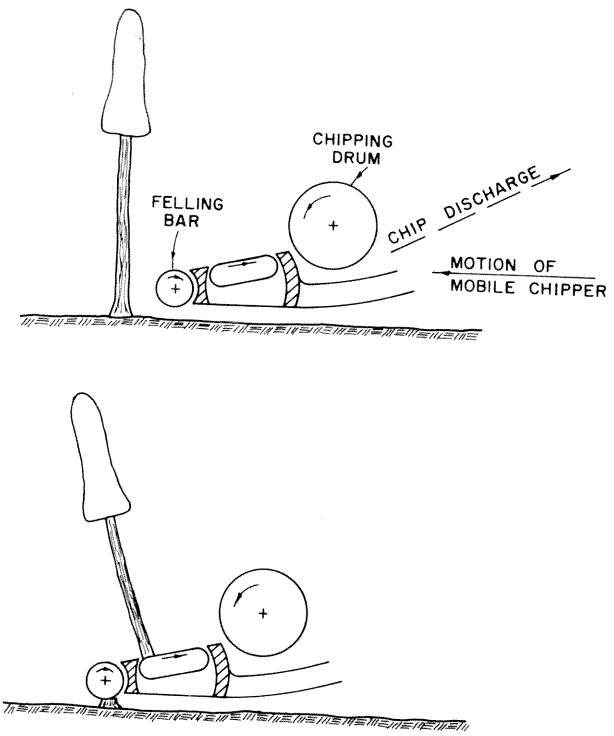


Figure 3.—*Concept of a mobile machine with a felling bar arranged to feed a drum chipper. (Drawing after Koch and Savage 1980.)*

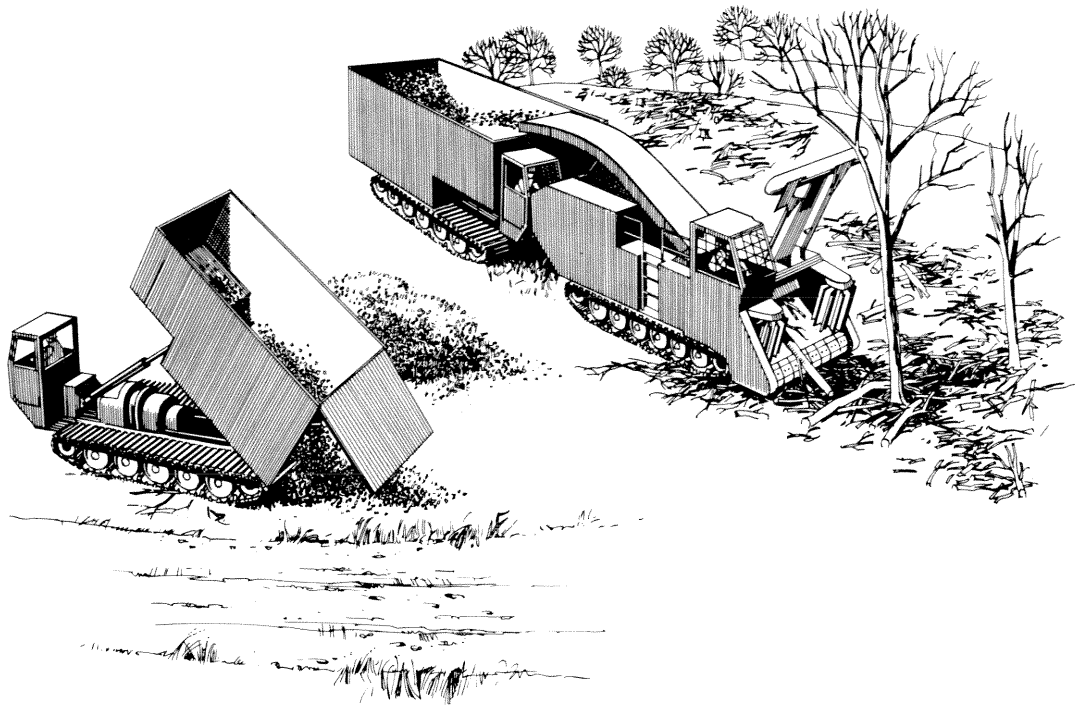


Figure 4.—*(Top) Mobile chipper and companion chip forwarders retrieve standing trees and logging slash as chips and deposit them in roadside inventory piles. (Drawing after Koch and Nicholson 1978.) (Bottom) Swathe-felling and chipping hardwoods while traveling 1 mile per hour.*

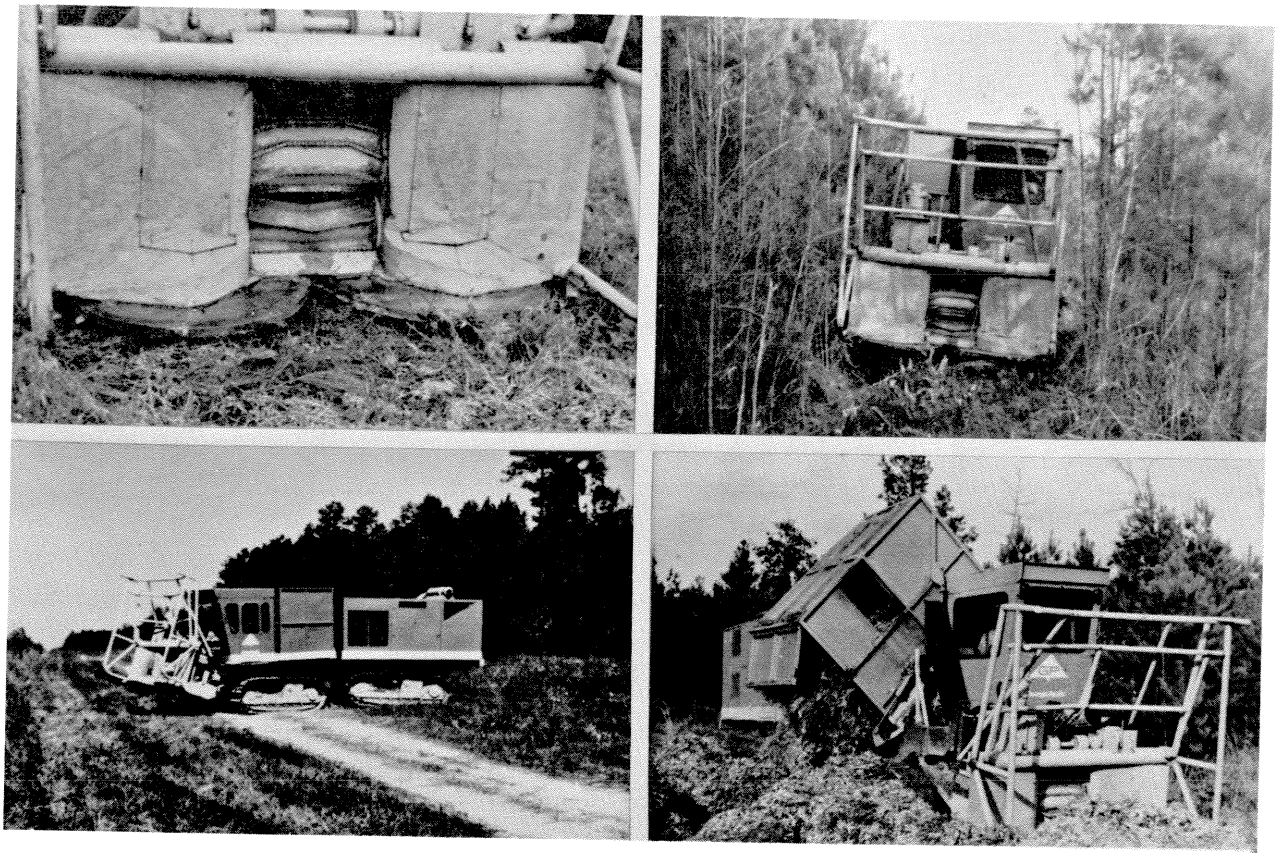


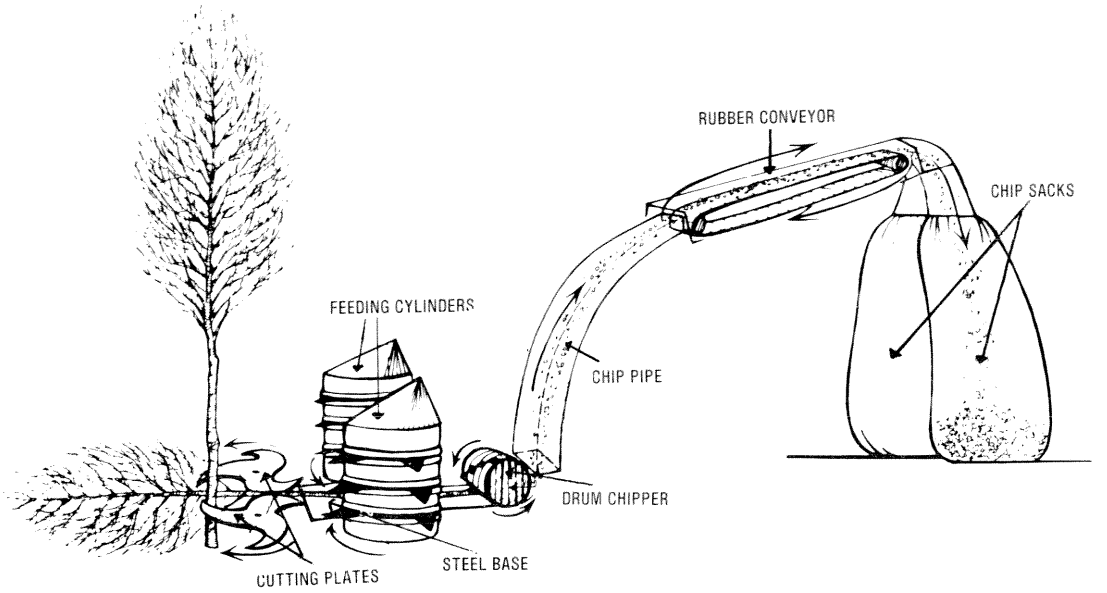
Figure 5.—*NFI/GP brush harvester. (Top left) Twin counter-rotating cutting disks that sever stems just about ground level and direct them into feed rolls leading to a drum chipper. (Top right) Front view from cleared swathe. (Lower left) Side view; grillwork on the front directs falling trees forward. The chip bin is directly behind operator's cab and the power unit trails. (Lower right) Chip bin self-dumps at roadside. (Photos from J. O'Dair, NFI.)*

CHIP WHOLE TREES AT THE LANDING

In a typical whole-tree chipping operation (fig. 7), an investment of about $600,000 is required (1979 basis). Equipment needs include a mobile roadside chipper capable of chipping whole hardwood trees with crowns attached, two feller-bunchers, and two grapple skidders. Also needed are a fifth-wheel tractor for spotting setout trailers in the woods, two fifth-wheel mainhaul tractors for highway transport, seven chip vans, and support equipment for maintenance. Such operations require 8-man to 10-man crews, producing about 400 cords weekly, or 8 cords per man-day (Warren and Kluender 1978). Recent studies of such operations on pine-site hardwoods indicate a cost of about $15 per green ton of chips delivered to the mill, before addition of profit on investment.

EXTRACT SAWLOGS AT LANDING—THEN CHIP, CHUNK, OR BALE BRANCHES

Sawlogs and veneer bolts are removed prior to some whole-tree chipping operations in which the unmerchantable tops and all remaining standing stems larger than 3 or 4 inches are brought to a landing for chipping. In others, sawlogs or veneer bolts are separated at the landing with the remainder being chipped. Studies in the North Central states indicate that a minimum of about 10 tons (green basis) of hardwood sawlogs must be obtainable per acre to justify sawlog sorting prior to whole-tree chipping (USDA Forest Service, North Central Forest Experiment Station 1978, p. 55). Graves et al. (1977) concluded that sawlog and veneer log sorting was economical if the value of such roundwood exceeds $26 to $40 per cord at the landing, depending on the system used.



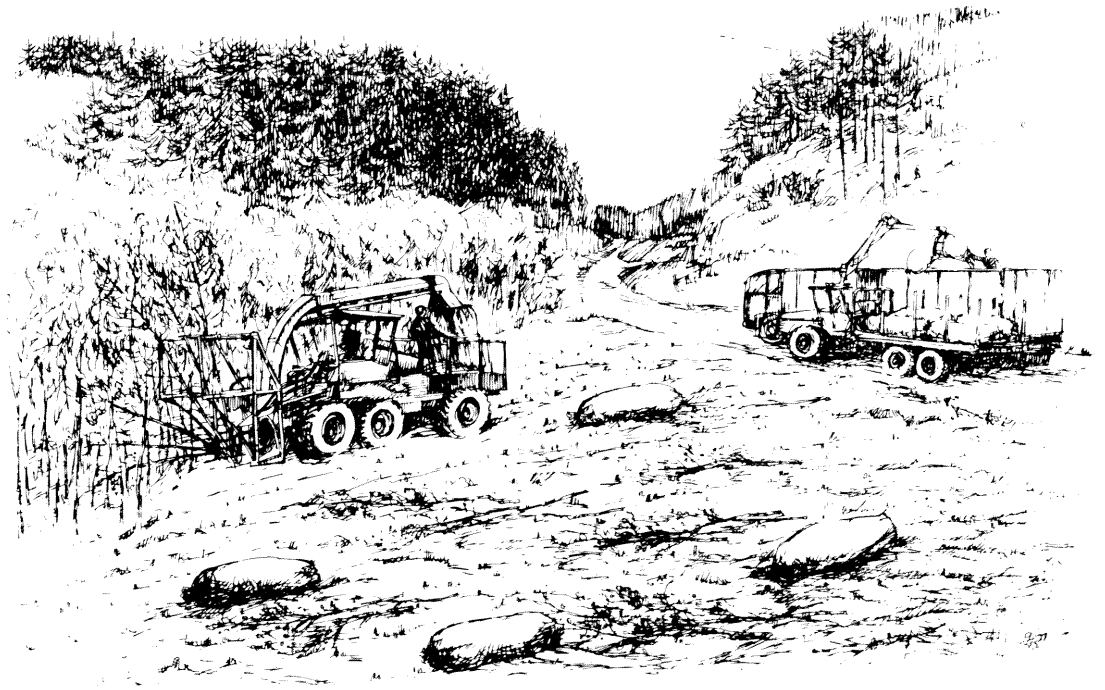


Figure 5A.—*Pallari swathe harvester. (Top) Principle of operation. (Bottom) Harvester in action, temporary chip storage in sacks, sack forwarder, and roadside discharge of sacks into a chip trailer. (Drawings from Hakkila and Kalaja 1980.)*

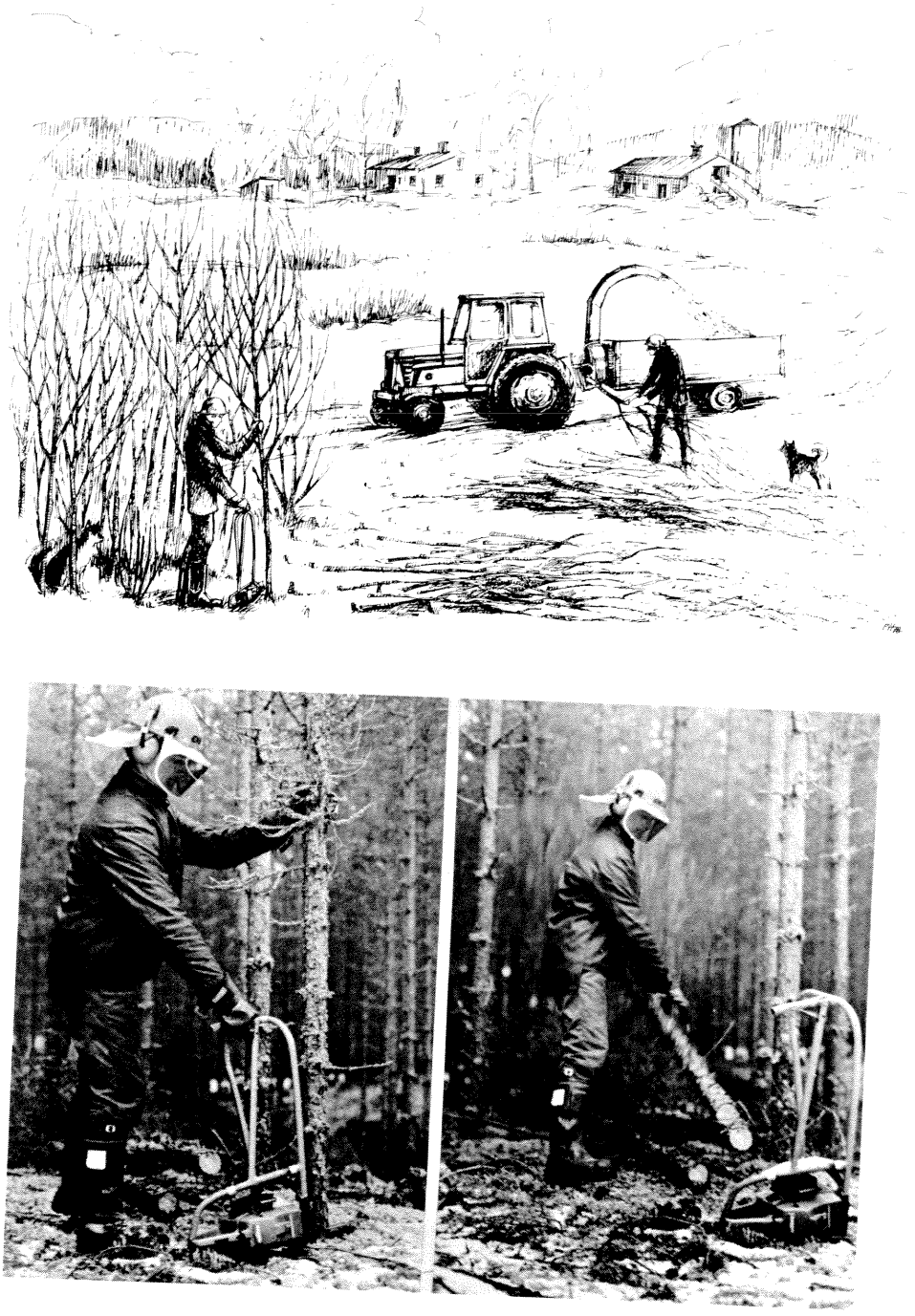


Figure 6.—*(Top) Two-man team harvesting whole-tree chips for fuel using a chainsaw equipped with a felling frame (to avoid stoop labor), and a light farm tractor powering a brush chipper. Daily output is 8 to 9 tons (green basis) for the two-man team. (Drawing after Hakkila et al. 1979). (Bottom left) Felling a small tree with a frame-mounted chainsaw. (Bottom right) Manual bunching of trees. (Photos from files of P. Hakkila.)*

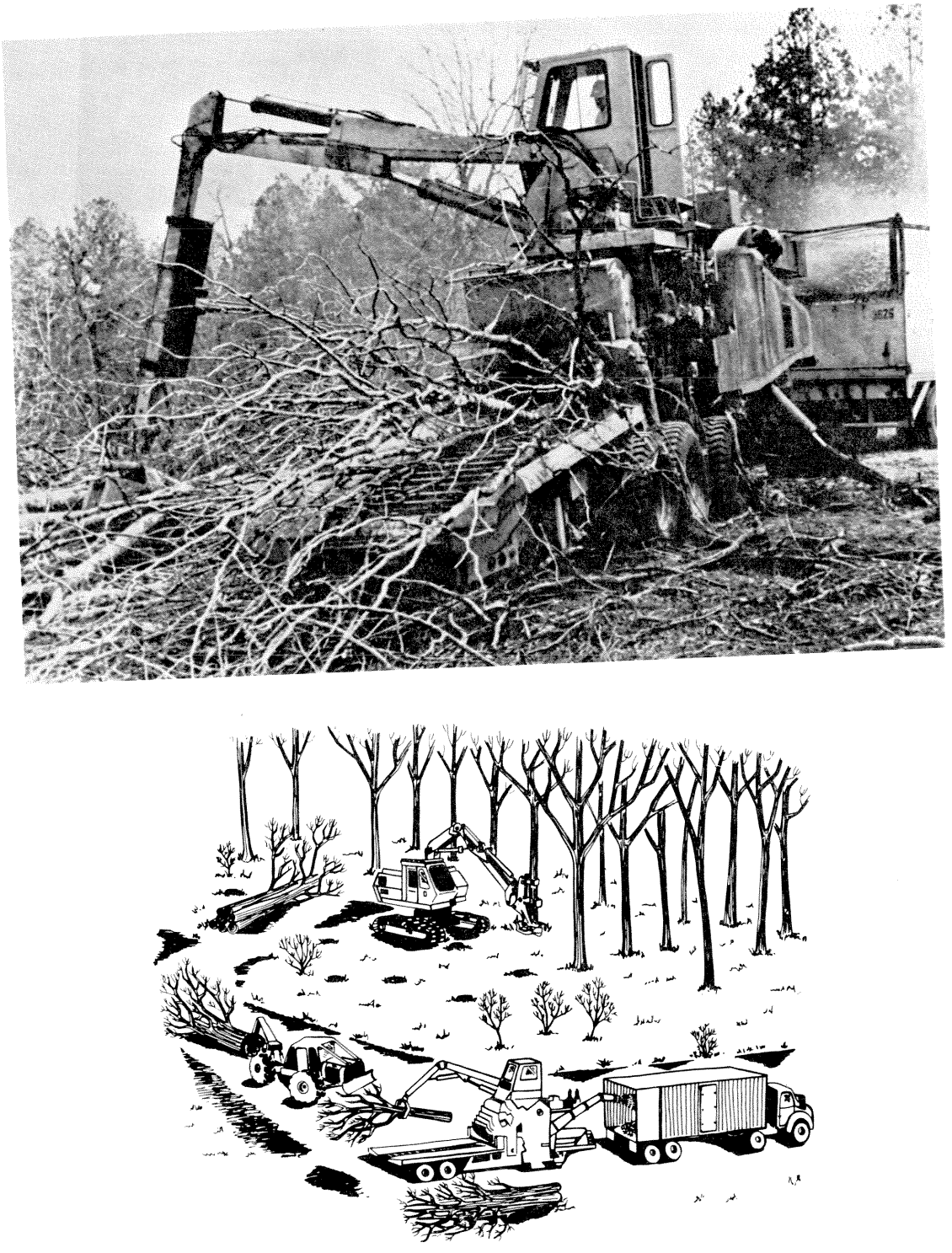


Figure 7.—*(Top) Self-feeding, whole-tree chipper at roadside landing processing pine-site hardwoods. The machine carries a 575-horsepower diesel engine and can continuously chip white oak stems 11 inches in diameter. Stem to 22 inches in diameter can be chipped with intermittent feed. Chips are blown into vans for transport to the mill. (Photo from Nicholson Manufacturing Company.) (Bottom) Typical whole-tree chipping system (Drawing after Biltonen et al. 1976.)*

Figure 9 shows a running skyline yarder teamed with a whole tree chipper in a major operation harvesting hardwoods from the steep hills of the Virginias. With this system, whole trees are deposited on the landing, and high grade logs are removed by chainsaw before the loader feeds remaining tops and stems into the whole-tree chipper, thus clearing the landing. Landings are bulldozed to accommodate the yarder, the chipper, two chip vans, two skidders, and a log truck.

Ordinarily clearcuts are 40 acres or less. Typically, the yarder is moved twice in a 40-acre set while the tractor that anchors the tail of the skyline (downhill or uphill, and about 800 feet away from the yarder) is moved 12 to 15 times. Virtually every tree, regardless of size, is dropped and skidded from the set. Production averages 200 tons of whole-tree chips per 8-hour day; another 15 tons leave the landing daily in the form of sawlogs. Excluding the logging supervisor, 11 men make up the crew. Three work under the carriage (a rigger and two choker setters), two operate chainsaws, one runs the yarder, and one operates the chipper. One man switches chip trailers, another unhooks chokers at the landing, and two men operate rubber-tired skidders. Additionally, a mechanic is available on call. Saw logs diverted from the chipper and chip vans are hauled by an independent operator (Pulpwood Production and Saw Mill Logging 1973).

Some operators find it difficult to work machines to their capacities in such a continuous-flow logging operation. They therefore yard stems into cold decks; at a later date a grapple skidder feeds the whole-tree chipper from the cold deck.

Mechanized machines for delimbing and log recovery.—The job of delimbing hardwood trees and extracting saw logs with a chainsaw (fig. 9) is hard, dangerous work. Highly mechanized roadside machines for delimbing and dismembering hardwoods are not yet available, but something like the Hahn harvester (Larson 1978), with added provision to sever limbs into chunks, is envisioned (fig. 10). The chunks would later be chipped for energy wood at a central location.

Swathe-cutting feller-buncher teamed with a log-separation and branch baling operation.—Feller-bunchers in wide use shear one stem at a time and accumulate several stems before dropping them to the ground. For small stems, however, this is slow (i.e., up to about 120 stems per hour) because the shearing head must approach each tree individually. Needed is a practical machine for

Figure 8.—*(Top) Experimental topwood harvester shearing and aligning limbs of hardwood tops. (Center) Typical hardwood top. (Bottom) Compacted top. (Photo from Mattson et al. 1978.)*

pine-site hardwoods and brush that will cut a swathe about 8 feet wide, severing at ground level everything in its path, while holding the severed trees to accumulate a suitable load for the grapple skidder. Conifers, with small crowns, afford easier solution than do the wide-crowned hardwoods. At least two prototypes have been built to test this idea on conifers—the Prince Albert Pulpwood machine (Stock 1978) and the Hydro-Ax swath-cutter (Davidson 1978). Both use thick circular saws to sever all stems at groundline in a swathe several feet wide while the machine travels at 1 mile per hour or faster and accumulates a dozen or more severed trees before dropping them in a

bunch. The Hydro-Ax has cut and bunched more than four trees per minute; in dense stands of very small spruce and fir the Prince Albert Pulpwood machine has averaged 25 trees per minute.

The rationale for development of a swathe-cutting feller-buncher is clear; its practical execution in a form appropriate for heavy-crowned small hardwoods is difficult, but probably not impossible. Assuming that resulting bunches can be ground skidded (or skyline yarded free of the ground) to roadside, they could then be separated at roadside into components to maximize value. Removal of stiff, strong limbs from multiple stems of hardwoods is a very difficult job, however. Assuming that this step can be accomplished, Walbridge and Stuart (1978) concluded that it should be possible to bale limbs and tops, and have proposed some prototype machinery (Stuart and Walbridge 1976, Stuart et al.[2], Stuart et al. 1980). Whole trees would be skidded to the landing, and left alongside the loader-baler machine where they would be delimbed and topped. The loader would not only load merchantable stems onto logging trucks, but would feed limbs and tops into a baler located beneath the loader (fig. 11).

Bales would measure about 3 feet square in end section and 3 or 4 feet long; with bulk density of 40 to 45 pounds per cubic foot, bales should weigh 1,500 to 1,800 pounds. The baler is estimated to cost $30,000 to $50,000 (1979 basis).

An experimental baler, built by International Baler Corporation, Jacksonville, Florida, was delivered to Tidewater Manufacturing Company in Brunswick, Georgia, for trailer mounting with power unit and hydraulic system and controls. The baler then was delivered to Virginia Polytechnic Institute in the fall of 1980 for evaluation. About 150 bales have been produced to date from both green and dry hardwod residues. Development work is continuing and will concentrate on devising an automatic infeed mechanism, tying procedures, and methods to increase production.

[2]Stuart, W. B., R. G. Oderwald, J. N. Perumpral, and R. Williams. 1979. The development of engineering criteria for an in-woods baler. Final Report, USDA Forest Service, Contract 333927-1, March 16, 1979.

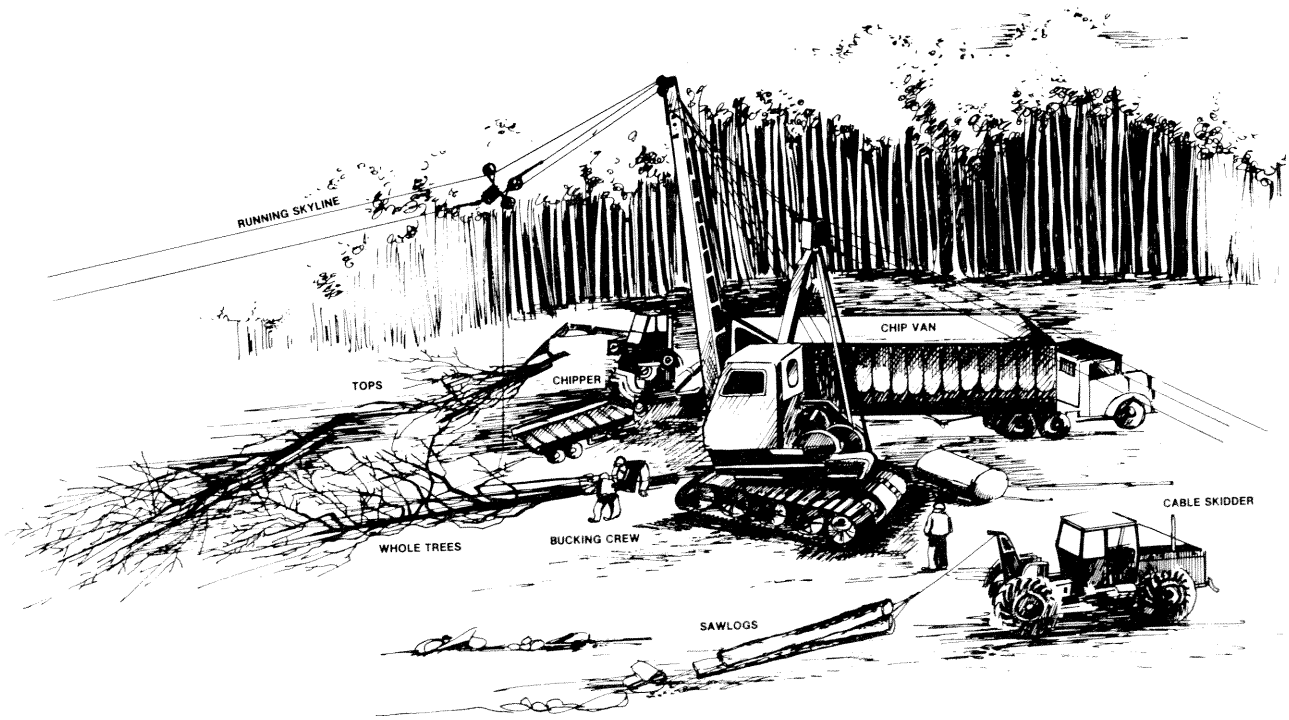


Figure 9.—*In this West Virginia operation on steep terrain, a running skyline yards entire hardwood trees to the landing, where chokers are released. Sawlogs of high quality are extracted by chainsaw. The loader feeds tops to the whole-tree chipper which blows resultant chips into a waiting van. (Drawing after photo from Westvaco Corporation.)*

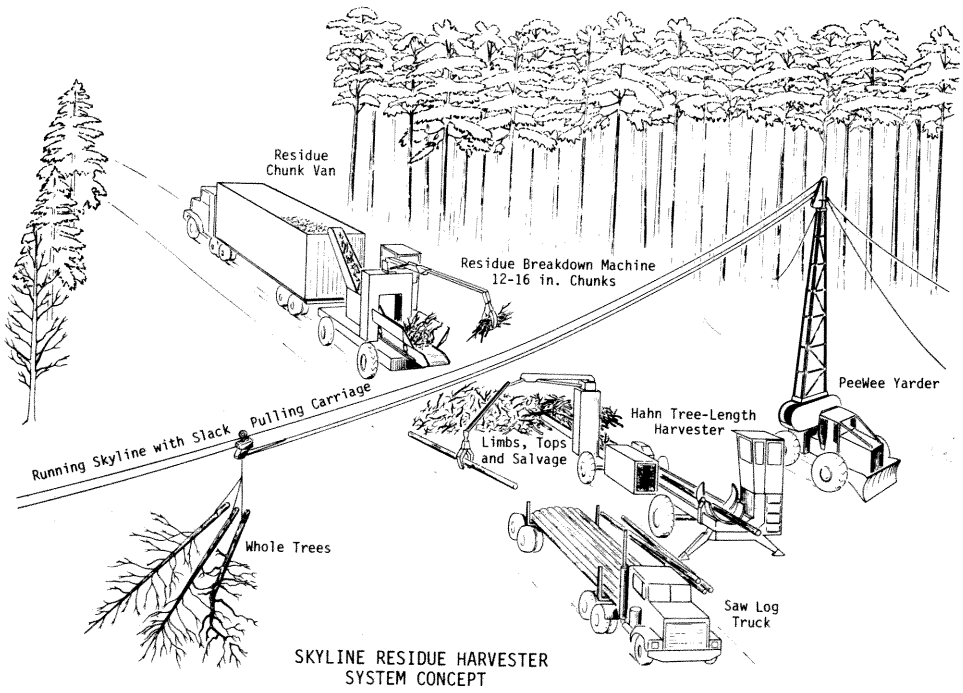


Figure 10.—*(Top) Hahn harvester shear-delimbing aspen* (Populus tremuloides *Michx.) and sawing stems into logs or bolts. Machine functions are powered by a 160-hp diesel engine. The harvester is roadable and can process about 840 stems per 8-hour shift. (Photo from Hahn Machinery, Inc. Two Harbors, Minn.). (Bottom) Layout combining the Hahn harvester with a running skyline and, in a secondary operation, reducing limbs to chunks for highway transport. These chunks would later be chipped for fuel or fiber. (Drawing from a proposal by the Pacific Northwest Forest and Range Experiment Station, USDA Forest Service.)*

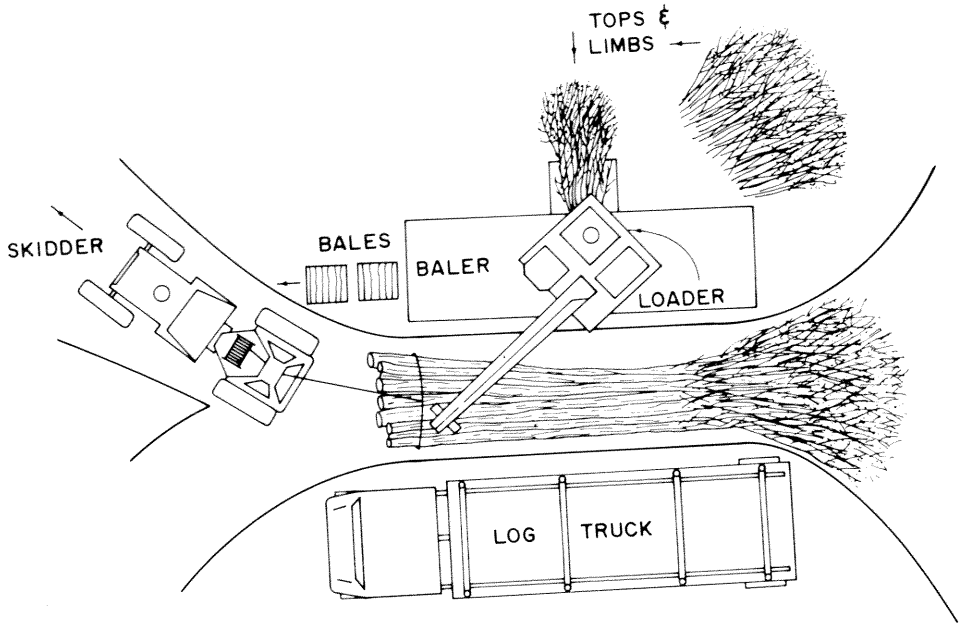


Figure 11.—*Concept for recovery of sawlogs followed by baling tops and limbs at the landing. (Top) Layout of landing where stems are delimbed, topped, and loaded on trucks; limbs are loader-fed, sheared to short lengths, and baled. (Bottom) Cubical bales are strapped with 10-gauge annealed wire, measure about 3 feet on a side, and weigh 1,500 to 1,800 pounds when green. (Drawing after Walbridge and Stuart 1978; photo from T. A. Walbridge, Jr.)*

CHIP RESIDUES—INCLUDING STUMP-ROOT SYSTEMS—AT THE MILL

As described in figures 10 and 11, it is possible to deliver tops and branches in the form of chunks or bales to an energy-producing plant where they can be chipped in a centralized facility.

Stump-root systems can also be extracted from the ground following primary harvest operations, and delivered to a central plant for chipping.

Stump pulling and processing.—Proponents of complete-tree utilization view the central stump-root system of pine-site hardwoods as a major source of wood for energy or fiber. These central stump-root systems, with lateral roots severed at a 1-foot radius, comprise about 15 percent of the weight of above- and below-ground tree biomass (ovendry basis) and about 28 percent of the weight of bark-free merchantable stems of small pine-site hardwoods. Ready availability of an unused wood resource of such magnitude is a strong incentive to devise practical stump harvesting methods. Moreover, removal of stumps in a commercial harvesting operation substantially reduces the cost of preparing the site for subsequent planting. Stump removal is not a new art. There were about 500 kinds of stump pullers on the American market in the 1800's, and stump pulling became a common American profession; two men with a yoke of oxen and a stump puller could travel indefinitely across the country pulling 20 to 50 stumps per day at $0.25 per stump—the standard price in 1850 (Sloan 1958).

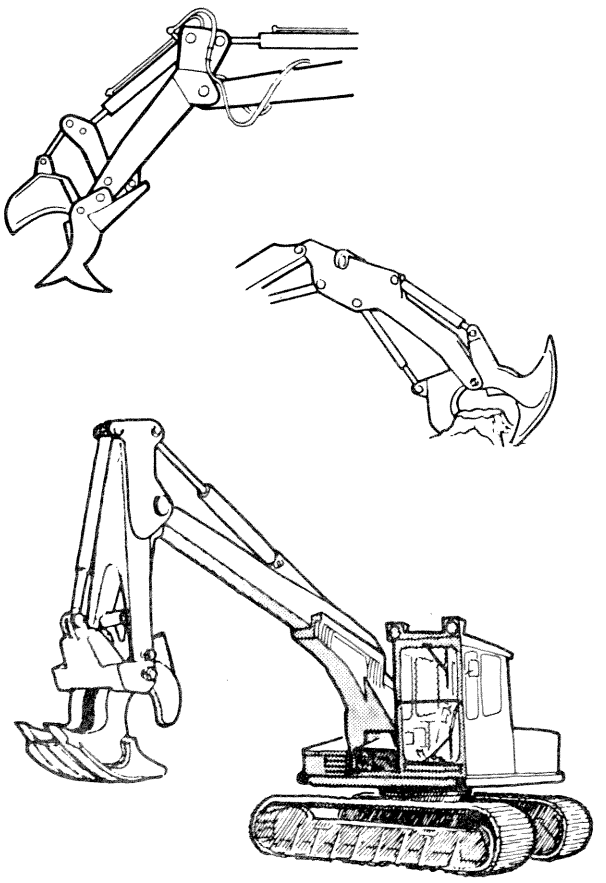


Figure 12.—*The Pallari stump harvester. (Top) Two designs of splitter-grapple head. (Bottom) Mounted on an excavator tracked chassis. (Drawing after Andersson et al. 1978.)*

Today, many entomologists, hydrologists, and soil scientists in the South view harvest of central stump-root systems with favor, because of diminished insect attraction to freshly exposed stump surfaces, improved percolation of water into many soils, and improvement of structure of some soils by the same mechanism as plowing of agricultural land. Uprooting is not unique to man-made forests; as noted by Stephens (1956), trees of the "primeval forest" had two general destinies: uprooting, or piece-by-piece disintegration in place.

Andersson et al. (1978) and Walker (1976) have reviewed equipment available worldwide to pull stumps after trees have been felled. Major machines for this purpose include:

Machine	Reference
Pallari stump harvester	Hakkila and Makela (1973, 1974)
Cranab stump harvester	Andersson et al. (1978)
Dynapac stump harvester	Andersson et al. (1978)
OSA stump harvester	Andersson et al. (1978)
Wick-Bartlet stump harvester	Harrison (1975)
Rockland roto lifter	Walker (1976)
Cavaceppi stump auger	FAO (1962)
STFI oscillating saw	Andersson (1975)
FLECO stump blade	USDA Forest Service (1971)
Bulldozer-mounted root rake	USDA Forest Service (1971)
Foster vibro stump extractor	Anonymous (1978)

The Pallari stump harvester appears well adapted to harvesting stumps of pine-site hardwoods. Several versions of the machine were designed in Finland in 1975-1977 (fig. 12). The unit is generally

mounted on an excavator-type crawler tractor, but tests have also been made on a feller-buncher chassis. Andersson et al. (1978) note that the machine, which is simple and reliable, can pull individual stumps and split them to the desired degrees of fragmentation. Blomqvist (1978) reported that, in commercial practice, the Pallari stump harvester produces 6.4 cubic meters (loose-wood basis) per hour and that cost of rootwood so harvested is $8.40 per cubic meter (loose-wood basis) delivered to the mill; transport distance to this mill averages about 25 miles.

The OSA 635 prototype stump harvester also appears to have some potential for pine-site hardwoods. The machine consists of a frame, a falling weight, and four movable knives. The falling weight drives the knives into the stump, splitting it in a cruciform pattern (fig. 13 top). This operation also frees the stump. When mounted on a feller-buncher or excavator chassis, grapple claws (fig. 13 bottom) fitted to the splitter can split, lift, and load stumps at a rate of about 5 cubic meters of solid wood per hour (Andersson et al. 1978). These authors propose three systems to deliver stumpwood at three levels of cleanliness into trucks for highway transport to the mill; each is based on initial splitting, harvesting, and limited fragmentation of stumps, with subsequent processing as follows:

System description	Cost, delivered 60 miles to mill (solid wood basis)
	Dollars/cubic meter
Uncleaned wood	28.52
Partial cleaning of wood accomplished in the forwarder in transit to roadside	28.75
Intensive cleaning by hammermilling and screening at the landing before loading into trucks	32.43

Users of rootwood prefer it cleaned of dirt and rocks at time of harvest. To satisfy this need, the L. B. Foster Company, Pittsburgh, Pa., combined a vibrating grapple head with a hydraulic self-propelled loader in a prototype stump harvester (fig. 14). To pull and bunch a stump, the operator lowers the open grapple over the stump, with prongs rotated to avoid visible outstretched roots. Hydraulic pistons close the grapple prongs under the root system and the vibrator is started. The loader crane raises the grapple and extracts the stump-root system. Excess dirt is shaken off as the operator swings the vibrating stump-root to the bunching area, where it is dropped when clean. This cycle, as observed in experimental runs, takes 90 seconds or less. A grapple sized to pull 24-inch stumps weighs 3,000 pounds (Anonymous 1978).

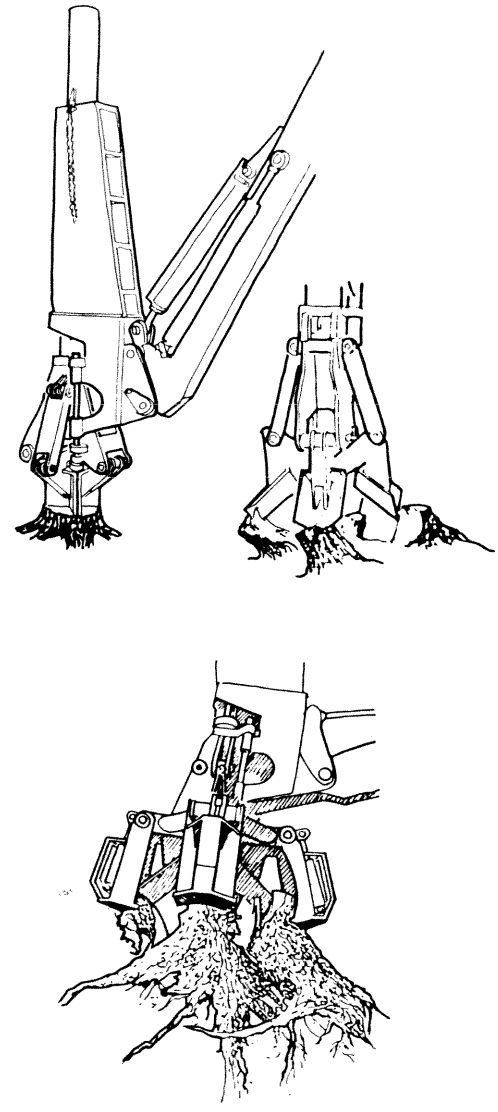


Figure 13.—*ÖSA stump harvester. (Top) Splitter. (Bottom) Splitter compined with a grapple for mounting on a feller-buncher chassis. (Drawing after Andersson et al. 1978.)*

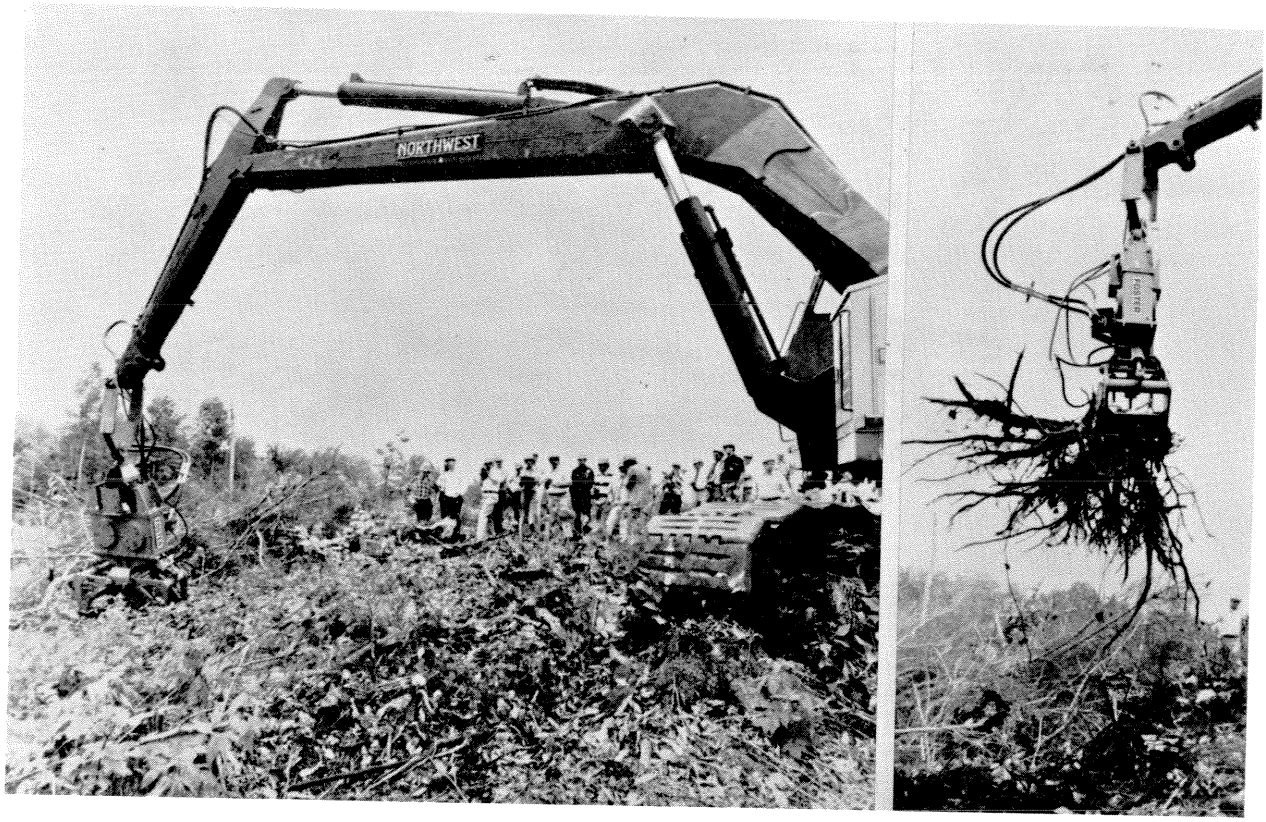


Figure 14—*Stump puller incorporating vibration device—just above grapple—to free stump from ground and loosen dirt from it. (Left) Grapple closing over stump. (Right) Extracted stump-root system. (Photos from L. B. Foster Company.)*

TRANSPORT COMPLETE TREES TO THE MILL

Whole trees, severed near ground level, can be bunched and loaded for transport, entire, to a centralized chipping plant at the energy-producing plant (figs. 15 and 16 top). Complete trees, with central root portions intact, can also be harvested and transported entire.

Tree puller-bunchers.—Most pine-site hardwood trees are small in diameter and not very heavy. A 6-inch southern red oak, for example, complete with crown and lateral roots to a 1-foot radius, weighs about 430 pounds—of which about 16 percent is in the stump-root system. Costs per ton for conventional felling and bunching are inversely proportional to the weight of the tree sections comprising the bunch. Harvesting the central stump-root system with the stem maximizes weight per section and should improve efficiency.

Two tree pullers potentially practical for southern forest operations have been invented. One pulls trees including entire lateral root systems, which are subsequently sheared and left on the ground. It has the advantage of an adjustable-diameter shear to accommodate trees of varying diameters (Sederholm 1976). This machine is not further discussed because no data are available on its operation on hardwoods, for which pulling forces with lateral roots intact are very large.

The second machine, jointly developed by the Southern Forest Experiment Station of the USDA Forest Service and Rome Industries (Koch 1976), leaves lateral roots in place in the soil; only the central stump-root system is harvested. Machines of this design are in steady commercial operation in Florida pulling and bunching 45 to 90 small southern pines (to 12 inches dbh) per hour. Harvesting costs, including profit on equipment investment, total about $8.61 per green ton delivered in tree lengths to the kraft mill where both rootwood

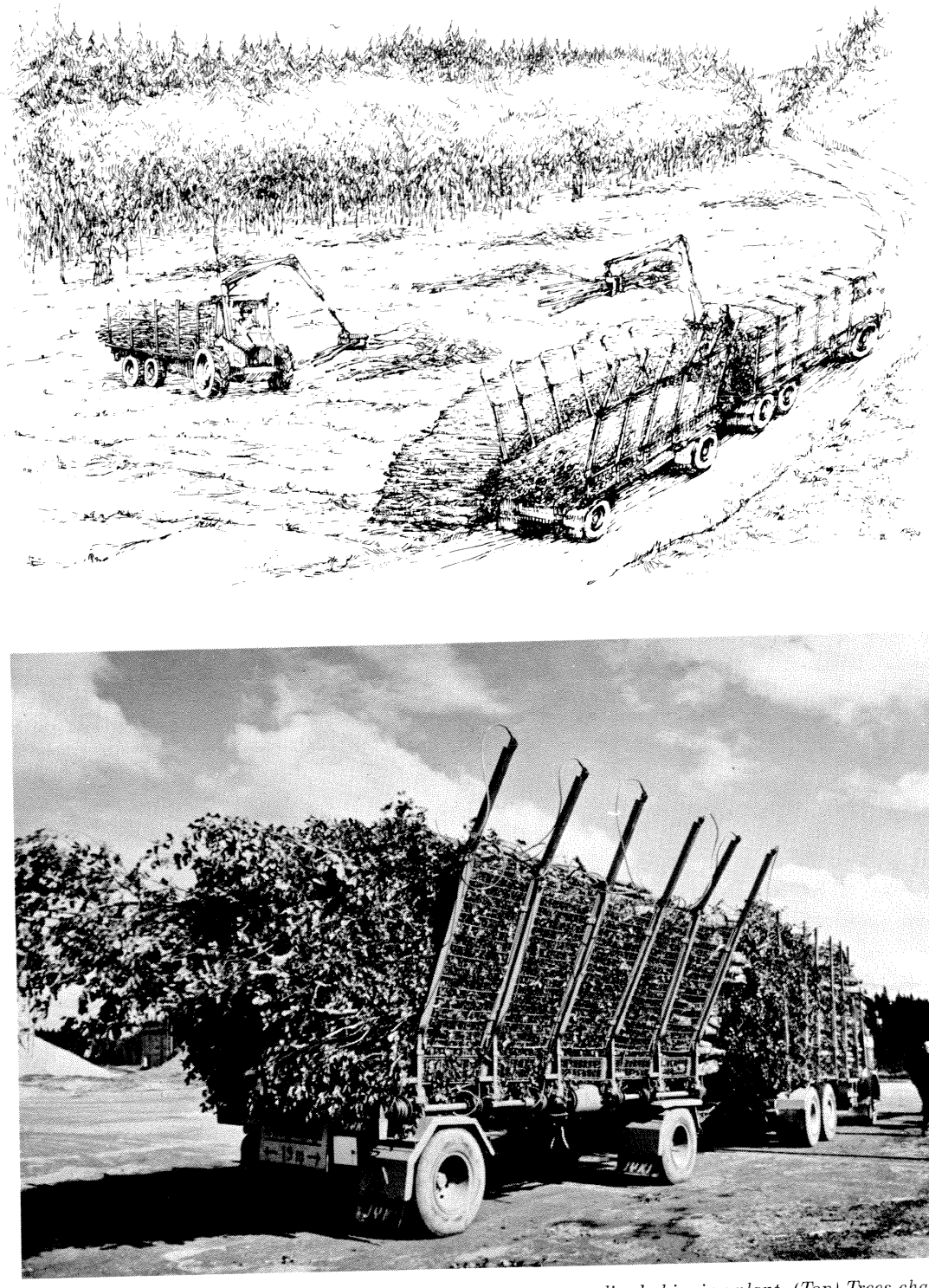


Figure 15.—*Harvest and transport of small whole trees to centralized chipping plant. (Top) Trees chainsaw felled and bunched as in figure 6, grapple loaded on forwarder, and reloaded at roadside on truck with bunk posts rigged to compress the load. (Drawing after Hakkila et al. 1979.) (Bottom) Whole-tree portions of speckled alder* (Alnus incana *(L.) Moench) loaded onto a trailer rigged to compress the load and contain it within legal space. (Photo from Yhteisostot Oy Jyki Tehtaat, Finland.)*

and stemwood are drum debarked and converted to pulp chips (Koch 1977). En route to the mill, trucks carrying the tree-length limb-free stems (with taproots attached) pass through a washing station consisting of two fire-hose nozzles swivel-mounted atop 6-foot stands, one on each side of a concrete slab. As each truck passes through the station, the driver washes his load; total delay time is 25 to 30 minutes per load (Davis and Hurley 1978).

Grillot and McDermid (1977) found that in pine stands in west Florida, productivity of the machine when making clear cuts was 16 cords per machine-hour; when thinning it was less productive, averaging only 7 cords per hour because of the smaller average size of trees.

The tree puller, manufactured by Rome Industries, Cedartown, Ga., can be fitted through a quick-hitch mechanism on a number of prime movers—for example, a Caterpillar 920 or a John Deere 544B (figs. 1 and 17). Two elements are essential to the design (fig. 18). The first is a scissors-type grip achieved with a pair of stout horizontal knife blades that close at groundline and bite several inches into the stem from opposite sides.

With this grip anchor, the second element in the design comes into action. It is a clamshell-hinged tubular shear, 22 inches in diameter and made of ¾-inch-thick steel. The shear, sharpened on the lower edge, is forced vertically into the ground to a depth of 10 inches, thereby severing lateral roots all around the tree. At this point, broad steps on opposite sides of the shear strike the ground and limit further penetration. An additional stroke of the hydraulic cylinder raises the grips 9 inches while the steps remain pressed against the soil surface. The effect is to jack the stem and break it free of the ground. Finally, the complete tree is lifted into the air and bunched for skidding. Since shearing takes only a few seconds, a tree can be harvested and bunched in about 45 seconds.

Dirt and rocks that adhere to the stump root system can present problems, expecially in clay soils. Hardwood stump root systems are more difficult to clean than the more compact roots of the southern pines. With pines, much dirt is shaken free during bunching, skidding, and stacking; washing en route to the mill dislodges more dirt, and finally a drum debarker can remove most of what remains so that bark-free (and remarkably dirt-free) root wood emerges from the drum debarker to pass through disk chippers and hence into the mill.

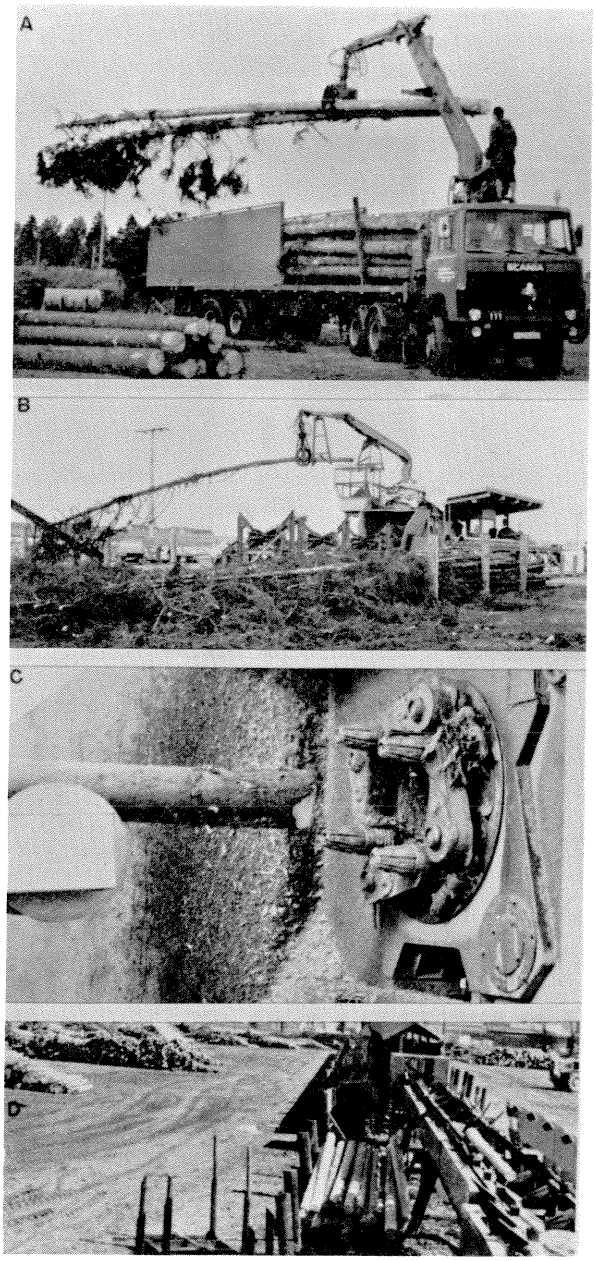


Figure 16.—*(A) Whole trees arriving at a tree merchandiser (B) Whole trees being grapple-loaded onto the infeed rolls of the delimbing machine (C) Rotating rolls equipped with knives delimb stems at 120 to 150 feet per minute; limbs are used for fuel or fiber. (D) Delimbed stems, after passing through a mechanical ring debarker, are crosscut for maximum value into poles, logs, and bolts. (Photos from Kwasnitschka 1978.)*

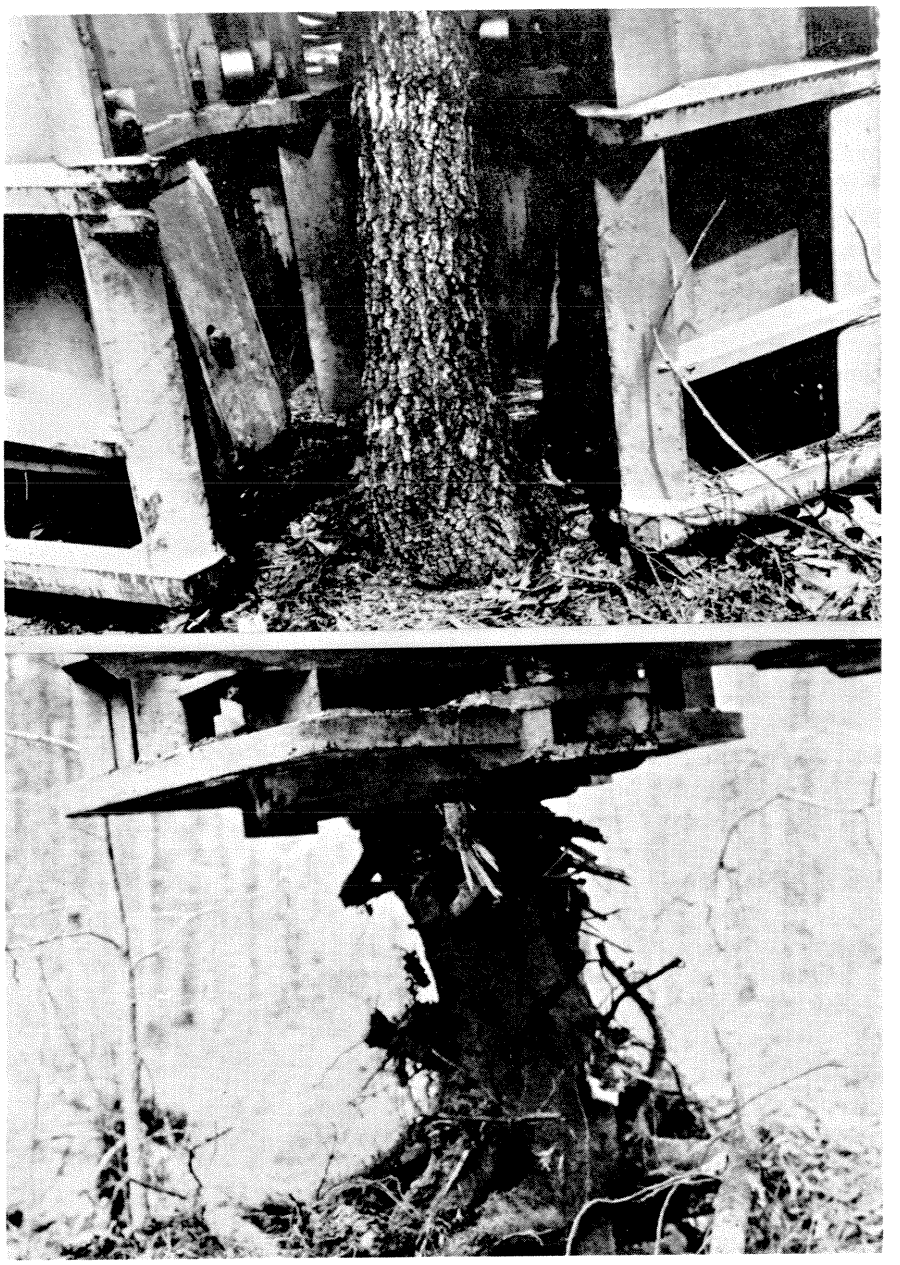


Figure 17.—*(Top) Tree puller-buncher poised to grip 8-inch southern red oak at groundline. (Bottom) Hickory tree pulled from ground after lateral roots near surface were severed, leaving central root mass intact. (Photos from D. Sirois, Southern Forest Experiment Station, Forest Service—USDA, Auburn, Ala.)*

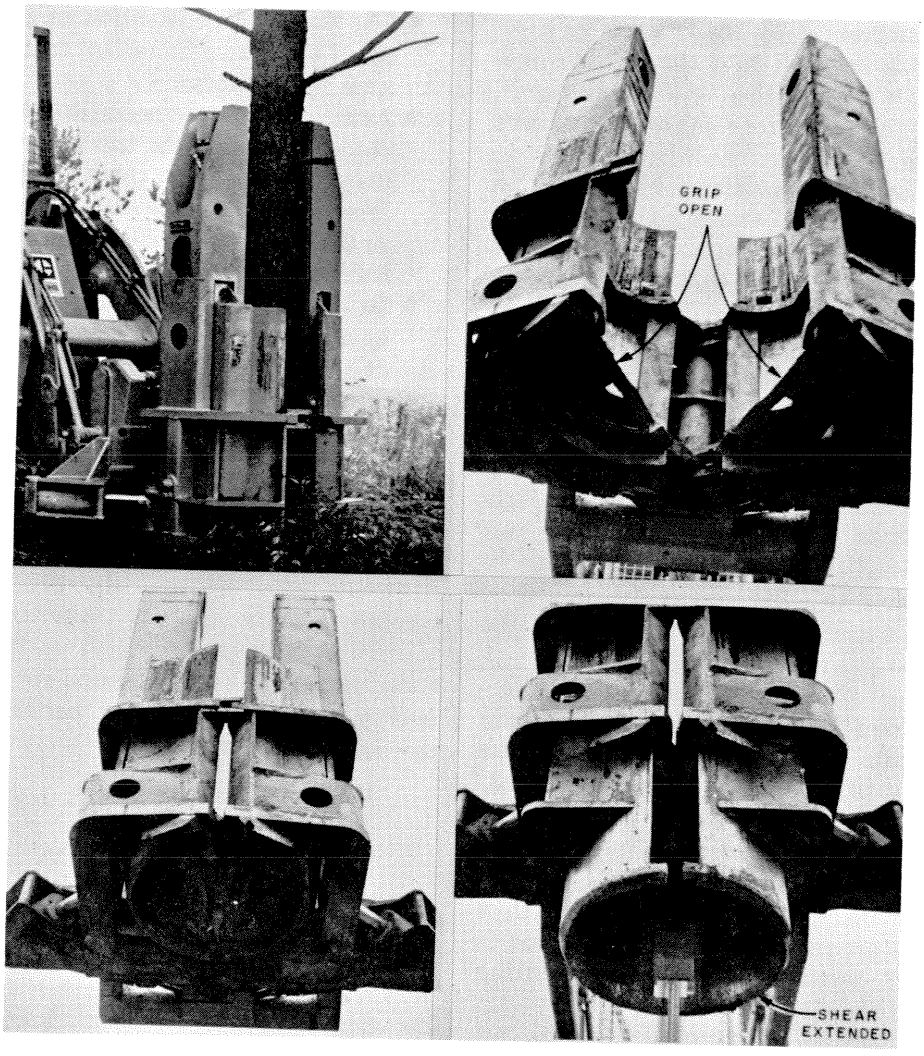


Figure 18.—*(Top left) Rome TX-1600 lateral root shear and tree puller mounted on a conventional four-wheel-drive articulated loader, with hinged grip closed on tree to be harvested. (Top right) View of gripping knives in open position with shear retracted. (Bottom left) Grip closed; in operation the knives grip the tree stem at ground level; no other grip is needed. (Bottom right) Grip closed and tubular shear fully extended 20 inches. Steps that bear against soil surfaces during last 9 inches of extension are visible on opposite outer sides of the shear tube. Each side of the tube is independently driven through its 20-inch stroke by a 6-inch hydraulic cylinder housed in the vertical column.*

Sandy sites harvested by the tree puller show few holes; dirt falls back into the cavities and leaves a hole only a few inches to a foot in depth. These holes are filled up after rains and movement of machines over them.

To provide design information for modification of the Rome lateral root shear and tree puller to adapt it for use on southern hardwoods, Sirois (1977) collected data on stump-root biomass and on forces when shearing and pulling white oak, southern red oak, hickory sp., and sweetgum. In a 75-tree sample, green weight of the central stump-root system averaged 18 percent of the complete-tree weight of above- and below-ground parts. The harvested stump-root system weighed 22 percent as much as the total above-ground biomass. Harvested portions of the stump-root system had average green weight (when cleaned) of 104 pounds, with range from 79 to 164 pounds in trees that measured from 4 to 12 inches in dbh and averaged about 6.8 inches.

Hickories were the most difficult of the four species to extract because most have taproots with deep laterals. Because the lateral root shear penetrated only 10 to 12 inches into the ground, deeper laterals were not severed and pulling forces sometimes exceeded machine capability. Forces to shear laterals were greatest for the hickories, regression relationships indicating that more than 200,000 pounds are required to drive the shear to a 10- or 12-inch depth in clay-loam soils; lifting forces were less than 70,000 pounds.

The Rome tree puller tested has shear blades 16 inches long that grip the tree at its base. Trees 12 inches in dbh of all four species may have butt diameters in excess of 16 inches, thus preventing closure of the tubular shear with resultant inability to shear laterals around the complete tree circumference; when lateral roots are not completely severed, pulling forces may be excessive.

The machine as tested weighed about 30,000 pounds when mounted on a Caterpillar 930 wheeled loader, and ground bearing pressure was about 10 psi. In soft ground the machine sometimes penetrated the vegetative mat and became stuck.

From this test series, Sirois (1977) concluded that the equipment could be made to pull pine-site hardwoods on a production basis if modified and given operational limits as follows:

- The prime mover carrying the shear head should exert less ground pressure (about 6 psi) and be capable of exerting higher drawbar forces than normal wheeled loaders.
- The depth of penetration of the lateral root shear should be increased (mainly for sweetgum and hickory).
- Additional force is needed to close the scissor blades that grip the tree at groundline, thus insuring that the tubular shear is closed around the complete circumference of the tree so that all lateral roots will be severed during its cutting stroke.
- To keep machine cost and size within reason, an upper limit on tree size should be established at about 9 inches dbh.

Centralized processing plant for complete trees.—The wood industry applies the term merchandiser to a centralized facility that dismembers tree-length logs, whole trees including crowns, or complete trees including central stump systems as well as stems and crowns.

Figure 16 illustrates the principal involved whereby tree components are separated for diversion to their highest-value use. Branches, tops, bark, and central root systems are converted into energy chips. Stems yield bark-free pulpwood, saw logs, and veneer logs.

CONCLUSION

Potentially available processes to harvest energy wood are numerous and diverse. It is difficult, however, to profitably produce energy chips from southern forest residues at a price that consuming industries are willing to pay. Including a 30-percent pretax profit on harvesting investment, the cost of energy chips delivered into mill stockpiles will likely range from $18 to $30 per ton (green-weight, 1980 basis). During the next decade, a few practical systems should evolve—but not without much trial and error.

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